PS Insar Monitoring in Heavy Oil Operations*

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Abstract

This paper presents an overview of recent InSAR monitoring integrated within Enhanced Oil Recovery (EOR) applications. It highlights the advantages of InSAR in monitoring surface deformation for Heavy Oil operations, management and optimization. Steam EOR techniques for heavy oil production present significant risks in several areas: - Cost: steaming is expensive and it is essential that facilities are sized properly and steam is utilized efficiently - HSE: wells and caprock integrity are necessary for reducing environmental risks - Recovery: identification of bypassed zones and steam migration tracking are crucial for recovery optimization Reducing risks in heavy oil operations requires steam migration monitoring, caprock and well integrity surveillance. Traditional monitoring techniques are based on the measurement of production and injection rates, pressure and temperature. Because Heavy Oil reservoirs are generally shallow, caprock can be thin, and high pressures are required for steam injection activities, surface deformation monitoring is an additional tool that can assess steam chest expansion and enhance safety. Ground displacement monitoring using radar satellite interferometry (InSAR) is currently applied in California and Alberta for Cyclic Steam Stimulation (CSS), Steam Flooding (SF) and Steam Assisted Gravity Drainage (SAGD). InSAR measurements are acquired remotely, over wide areas and to high precision. Recent advances in InSAR data processing have enhanced the quality of measurements, as well as increased their spatial density. High-resolution sensors are now available, increasing spatial resolution to one square meter and acquisition frequencies to every few days. The main capability of InSAR monitoring in heavy oil operations is to highlight zones of excessive pressure or subsidence and to control the integrity and safety of operations and infrastructure. In addition, given the high density of natural radar targets, InSAR monitoring can also be used to interpret steam propagation and chamber growth. These capabilities have made InSAR monitoring an essential tool for the dynamic management of several EOR and steam injection projects, reducing their inherent risk and costs

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InSAR MONITORING IN HEAVY OIL OPERATIONS

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Introduction

This poster presents an overview of recent InSAR monitoring, integrated within Enhanced Oil Recovery (EOR) applications. It highlights the advantages of InSAR in monitoring surface deformation for Heavy Oil operations, management and optimization.

Steam EOR techniques for heavy oil production present significant risks in several areas:

- Cost: steaming is expensive and it is essential that facilities are sized properly and steam is utilized efficiently
- HSE: wells and caprock integrity are necessary for reducing environmental risks
- Recovery: identification of bypassed zones and steam migration tracking are crucial for recovery optimization

Reducing risks in heavy oil operations requires steam migration monitoring, caprock and well integrity surveillance. Traditional monitoring techniques are based on the measurement of production and injection rates, pressure and temperature.

Heavy Oil reservoirs are generally shallow, caprock can be thin, and high pressures are required for steam injection activities, surface deformation monitoring is an additional tool that can assess steam chest expansion and enhance safety.

Ground displacement monitoring using radar satellite interferometry (InSAR) is currently applied in California and Alberta for Cyclic Steam Stimulation (CSS), Steam Flooding (SF) and Steam Assisted Gravity Drainage (SAGD).

InSAR measurements are acquired remotely, over wide areas and to high precision. Recent advances in InSAR data processing have enhanced the quality of measurements, as well as increased their spatial density. High-resolution sensors are now available, increasing spatial resolution to one square meter and acquisition frequencies to every few days.

The main capability of InSAR monitoring in heavy oil operations is to highlight zones of excessive pressure or subsidence and to control the integrity and safety of operations and infrastructure. In addition, given the high density of natural radar targets, InSAR monitoring can also be used to interpret steam propagation and chamber growth.

These capabilities have made InSAR monitoring an essential tool for the dynamic management of several EOR and steam injection projects, reducing their inherent risk and costs.

Section 1: Understanding InSAR

InSAR stands for Interferometric Synthetic Aperture Radar.

Since the early 1990's, the first radar images of the Earth's surface obtained from Synthetic Aperture Radar (SAR) sensors mounted on satellites have stirred significant interest in the sector of Earth Observation, creating new ground monitoring opportunities for analysis of surface deformation phenomena. As a result:

- Satellite radar data can provide high-quality, remotely sensed data about surface deformation.
- Over time, the early processing algorithms have been significantly upgraded and are much more powerful today.
- Surface deformation measurements are gaining increasing attention within many engineering and geologist communities to complement, validate or replace conventional surveys using GPS or levelling techniques.
- New satellite monitoring techniques are relatively low in cost and their information content adds significant value, if properly interpreted and integrated with more conventional data.

Caculating InSAR Measurements

The satellites emit millisecond bursts of C-Band (5.3cm wavelength) or X-Band (3.1 cm wavelength) radar energy over selected locations of the Earths surface. (Figure 1)

Much of this radar energy is scattered or absorbed, but some is returned to the satellite as reflected energy. The satellites are considered coherent in that they emit and receive radar energy reflected from natural and artificial structures on the Earths surface. Over a typical heavy oil asset, the more obvious radar reflectors are buildings, oil and gas infrastructure such as wellheads, piping, pumps, and access roads.

Reflected radar energy comprises an Amplitude component, a measure of "brightness", how much of the incoming radar energy is returned to the satellite, and Phase.

In determining the elevation of a specific reflector the Phase data is of most interest. By knowing the wavelength of the emitted radar energy, and monitoring the number of phases returned from the surface reflector, it is possible to calculate the distance from the SAR satellite radar emitter to the reflector.

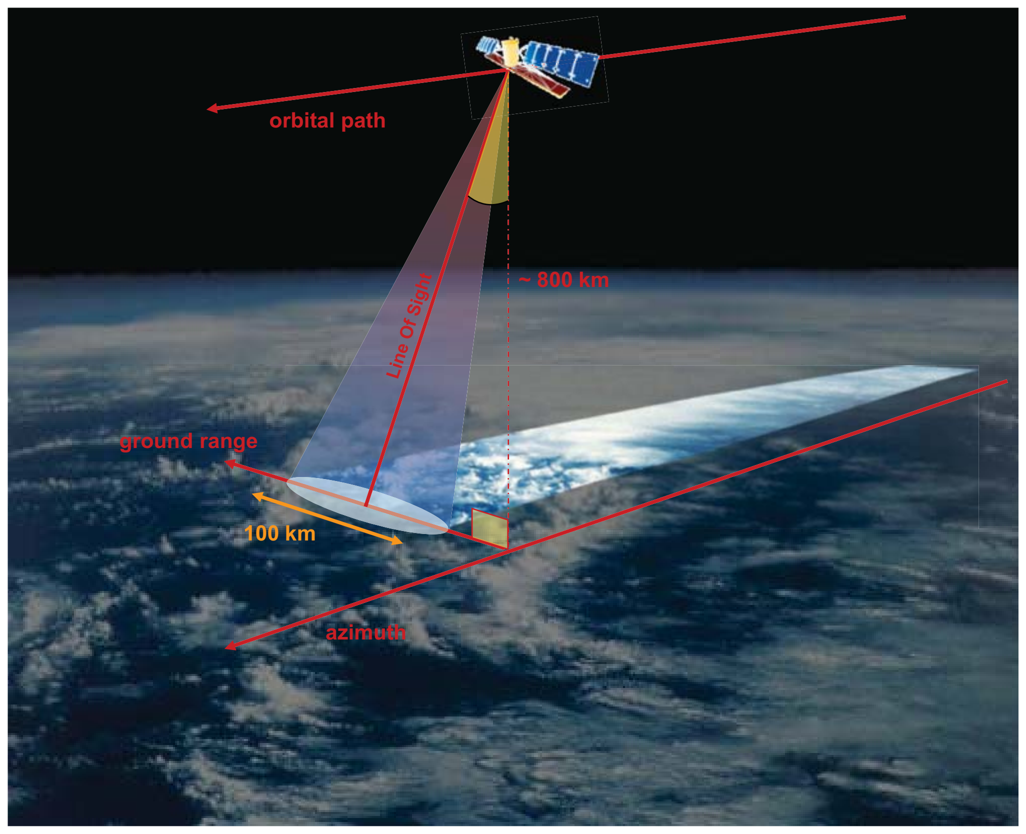

Figure 1. SAR radar satellites orbit the Earth every 90 minutes, at an altitude of 500 miles (800 km), travelling on a pole to pole orbit.

Interferometry

The comparison of Phase changes is referred to Interferometry. This is a relatively simple analytical technique that compares two satellite images together and looks for changes in the Phase component of the reflected signal as shown in the Figure 2.

If there are more phases seen in the reflected signal, then the elevation of that reflector is subsiding i.e. moving further away from the satellite. The converse is also true, if fewer phases are seen in the reflected signal then the reflector is moving towards the satellite.

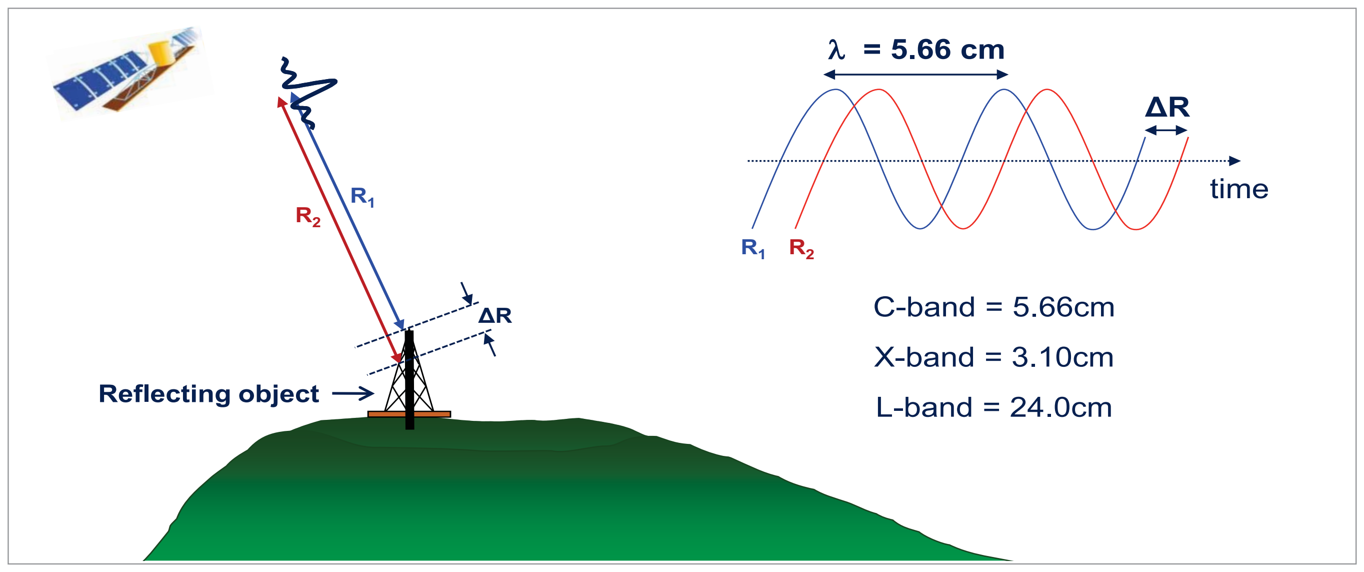

Figure 2. Interferometry - Comparison of Phase Changes.

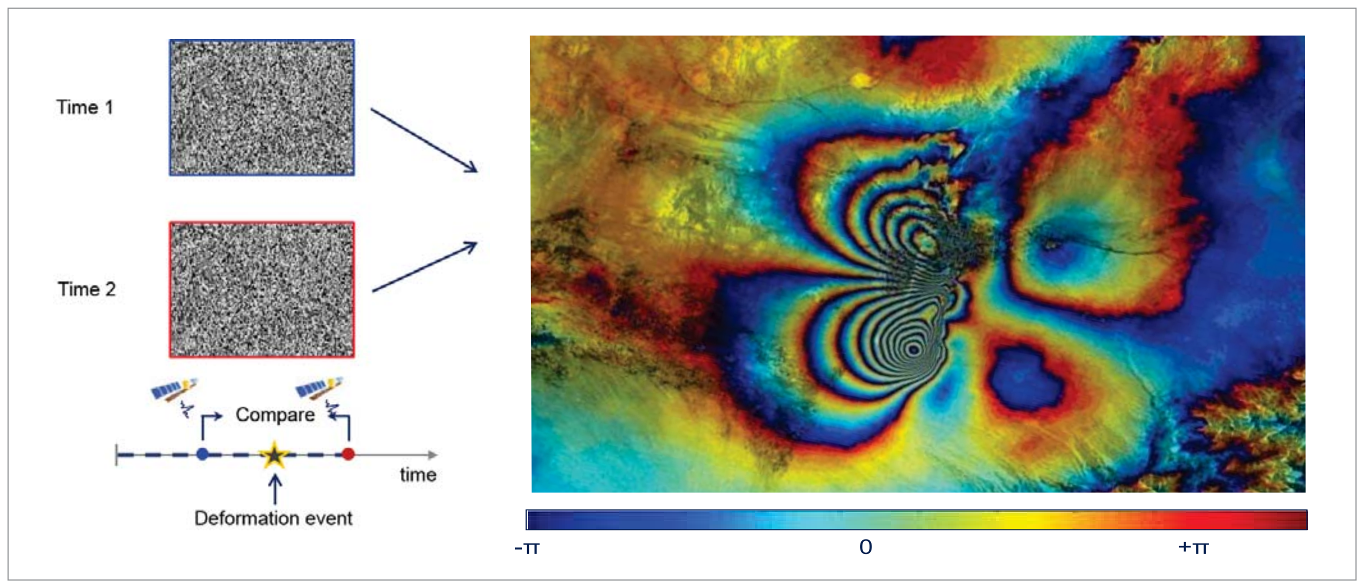

Figure 3. The interferogram example shown figure 3 is the 2003 Bam earthquake in Iran. Each complete coloured fringe represents a complete wavelength of motion. By counting the fringes, it is possible to calculate the total ground motion experienced in the area.

Interferometry to Displacement Maps

Where ground motion is much more modest it is possible to contour these interferograms to produce deformation maps. These maps show the changes in the elevation of the Earth's surface over the period of time between the two satellite images. Typically, individual interferogram have an elevation accuracy of plus or minus 2cm (Figure 4).

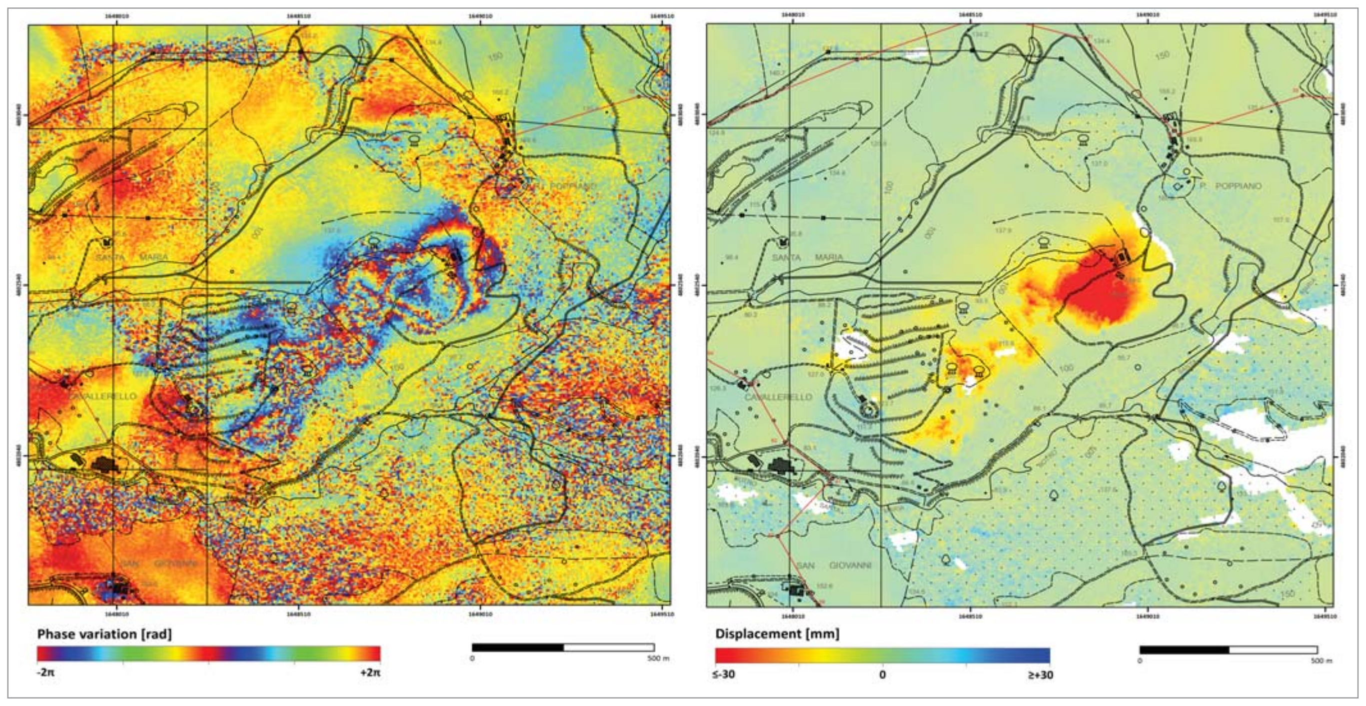

Figure 4. Displacement maps

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Section 2: Evolution of The Technique

Interferograms have some limitations, the largest of which is the inability to quantify and remove the effects of atmospheric changes present between images. These atmospheric effects can be related to clouds cover, storm events and changes in atmospheric moisture levels.

In an effort to remove the atmospheric influence from InSAR data, in the mid 1990's research was started at the University of Milan to increasing the accuracy of the InSAR analysis.

The result of these research efforts was the patenting of the PS or Permanent Scatterers algorithm by the university and the creation of TRE.

PSInSAR recognised that the presence of physically distinct surface reflectors appearing in the same location in all satellite imagery. By stacking sequential satellite images, it is possible to use the PS points to quantify and remove the effects of the atmospheric component. Once this component is removed then elevation accuracy increases to plus or minus 1mm. The first radar image used in SAR analysis is considered to be the baseline image. All subsequent measurements are referenced to the base line image and would show uplift, stability or subsidence.

Work continued to further refine the PSInSAR approach and research efforts focussed on the radar backscatter from open areas of country, where frequently there was no physical surface reflector.

Advanced Insar Technique: SqueeSAR™

Deformation points reported in these areas were called Distributed Scatterers and formed the basis for the SqueeSAR processing algorithm, launched in 2008. Distributed Scatterers are statistical constructs, grouping together pixels showing very similar radar reflective characteristics. These cohorts are resolved to define a single deformation point and the process is then repeated again in all adjacent pixels. This is obviously an intensive computational process but results in a significantly greater number of identified deformation data points.

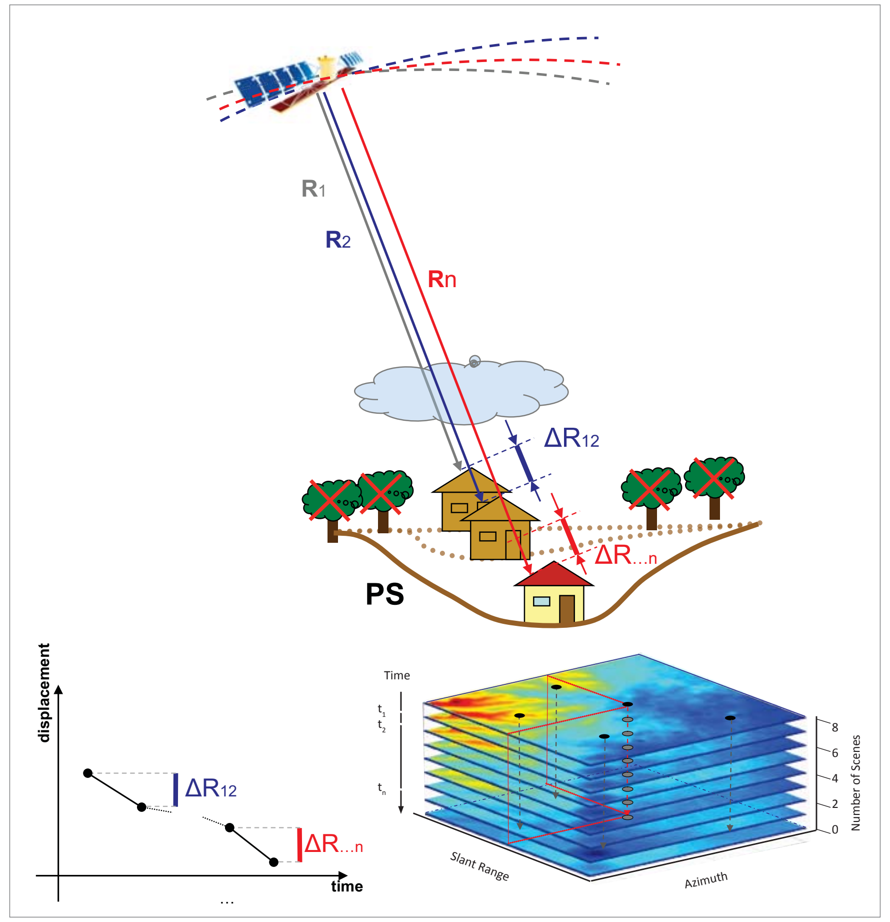

Figure 5. : By stacking interferograms into data sets and identifying individual Permanent Scatterers visible in each image, it is possible to resolve ground deformation to millimetric levels of accuracy. Sequential images also allow the tracking of non-linear ground motion

Many hundreds of individual deformation measurement points are colored according to the direction of cumulative movement. In the example below (Figure 6) red indicates uplift, blue subsidence, and green-yellow indicates stability.

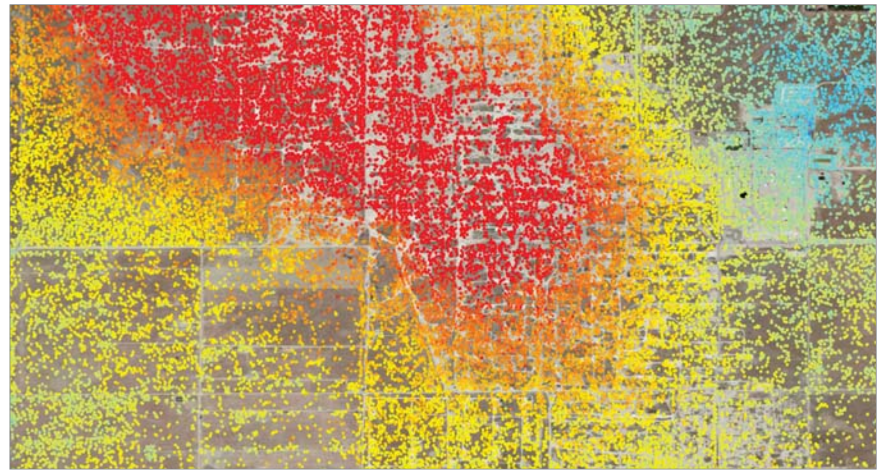

Figure 6: A typical SqueeSAR result.

By zooming into a portion of the field it is possible to see the change in surface elevation defining the location of the active steam chamber. (Figure 7)

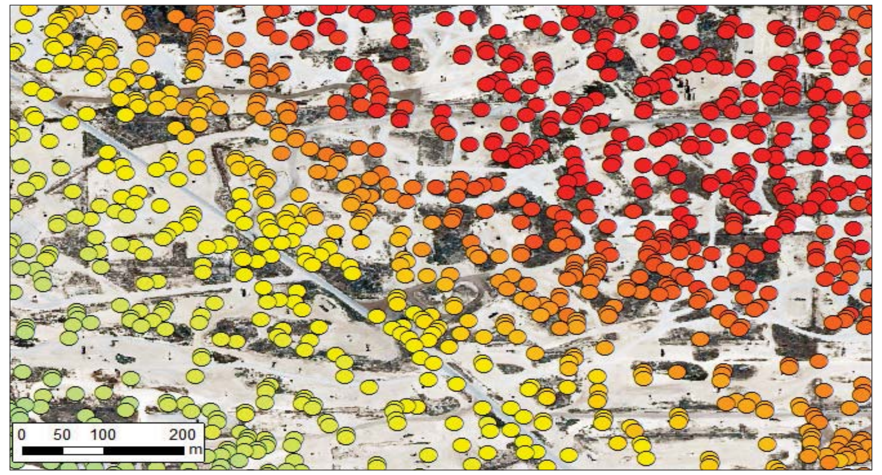

Figure 7: close up of the SqueeSAR result

Within the ArcGIS environment by clicking on an individual colored dot is it possible to pull up a record of the elevation at that single point called a time-series. The first satellite image is considered to be the zero point and therefore elevations fall on the zero line. Each subsequent image added to the data stack is processed, the PS or Permanent reflectors identified, and their elevations calculated. By adding many images to the data stack a record of nonlinear motion can be seen. In Figure 8 the single PS point is showing linear subsidence.

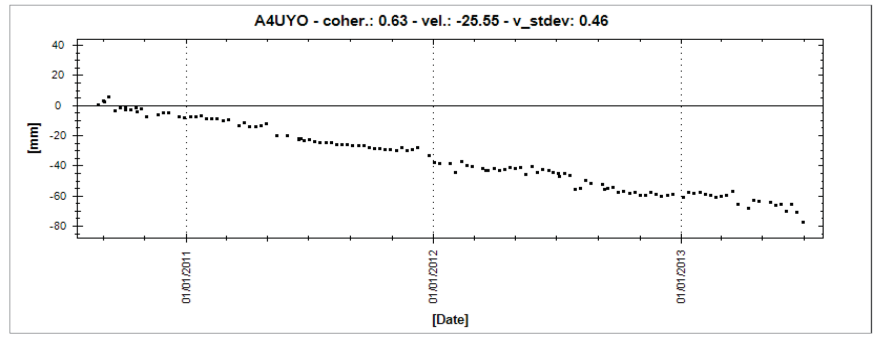

Figure 8: An example of a Time-Series

Section 3: The Uses of InSAR Data

Historical

The first of the SAR data was collected in the 1990's and extensive global archives were built up using ERS and Envisat data. These early datasets can be reprocessed using the modern SqueeSAR algorithms and often provide valuable historical ground deformation results. Several different satellite platforms have been launched in the intervening years. The satellites have become more sophisticated and revisit time for image repeats are now vary. Clients often request both a historical study and ongoing InSAR study over an area, allowing a history of ground motion to be defined and ongoing ground movement to be monitored.

Ongoing

In heavy oil applications using both steam and waterflood very often interferograms and SqueeSAR processing are used in combination. Interferograms can be supplied on 16-day increments, with a quarterly SqueeSAR processing to confirm and validate the interferometric results.

Because interferograms can be rapidly delivered and can indicate the amount and extent of rapid deformation events, they are frequently used to help actively manage fields.

- Defining the location of steam or water emplacement.
- Defining injector producer relationships and production polygons.
- Monitoring the amount of deformation created by specific injection cycles.
- Identifying upswept areas of the field not affected by steam or water injection.
- Identifying compartmentalization of the field showing areas of significant differential movement.
- Looking for wells, or groups of wells, at risk of casing failure due to excessive uplift or subsidence.
- Looking for well failures resulting in shallow injection.
- Cap rock integrity.
- Casing integrity.
- Fault activation, reactivation.
- Regulatory compliance.
- Integration of different surface and subsurface measurements.
- Artificial Corner Reflectors.
- Clients looking for lease boundary infractions; either their own, or by others operators.
- Benchmarking reservoir response against computer modeling, defining changes in reservoir porosity and permeability.

Advanced Reservoir Management

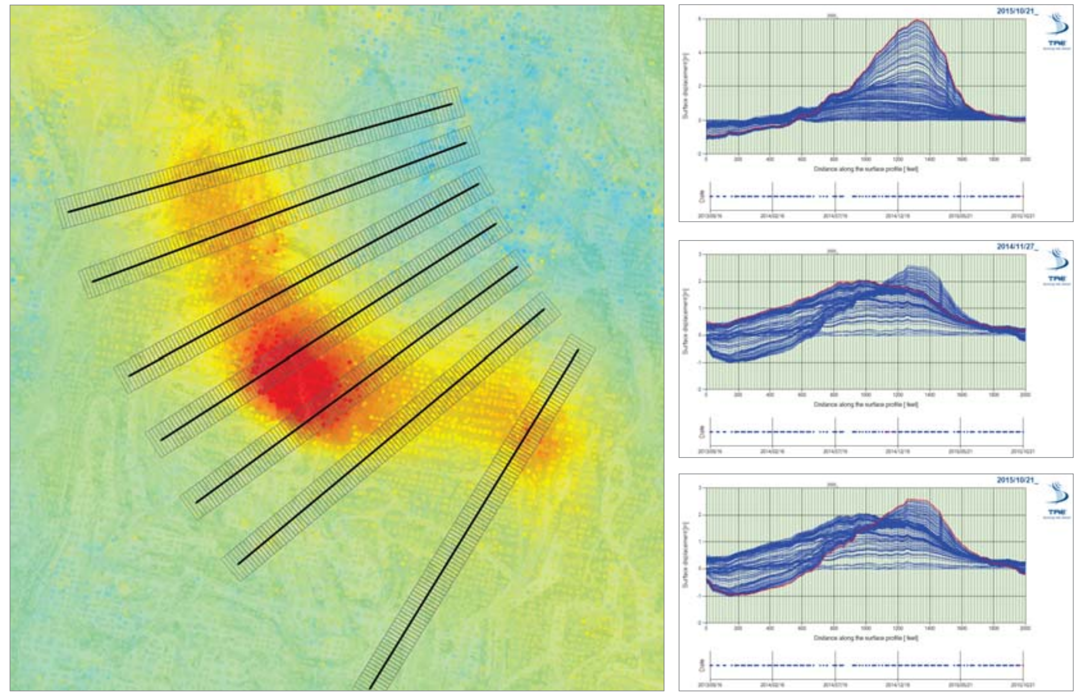

Figure 9: Location of Steam Emplacement and Movement

Cross-sections drawn through areas of uplift or subsidence can be used to dynamically illustrate the evolution of the ground surface elevation through time. By looking at the change in elevation relative to time it is possilble to see the progressive movement of steam or water through the reservoir.

Shallow Well Casing Failure

Well integrity is becoming an increasingly important monitoring role for InSAR data. In fields where one injector may influence four or more producers, it is possible to monitor injector health by looking for evidence of strong localised uplift in short temporal baseline interferograms.

Because interferograms can be delivered quickly they are very good method of identifying localised uplift related to shallow injection, as a result of casing failures.

Monitoring the health of producers is a more complete issue. Casing failures in producers may only be identified by:

- A single well may show poor production, below anticipated rates.
- Well production may be influenced by adjacent and unrelated injectors.
- Production may appear in casing annulus.
- Production may appear at surface near failed wells.

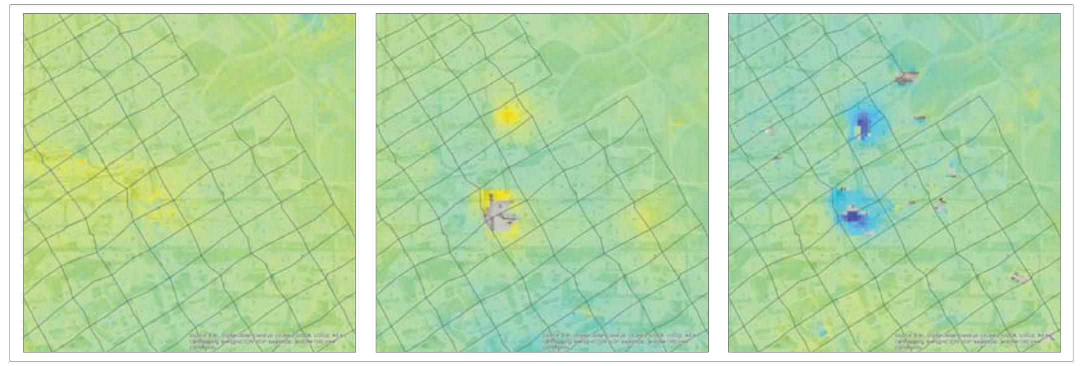

Figure 10: The three interferograms above are each seperated by 16 days. The first shows no unexpected ground motiion, the second shows three small areas of uplift in yellow as a result of shallow injection due to casing failure. The final image shows three areas of subsidence around the wells after injection was halted, the wells suspended and ground elevation returned to normal.

Section 4: Advanced Analysis for Interferogram and SqueeSAR Results

Heavy oil operators are increasingly looking to use observed ground deformation to help manage heavy oil production.

Given that there is regulatory pressure being applied to monitor heave, operators want to use deformation data to both meet regulator expectations and to limit the risk of well casing failures, reservoir collapse and possible surface expressions of steam, oil and water.

Increasing interest is being show with inverting observed surface deformation to depth and using ground motion as a component of geomodelling.

Interferograms sometimes show distinctive differential ground motion. Closer examination of the data can indicate the presence of a fault.

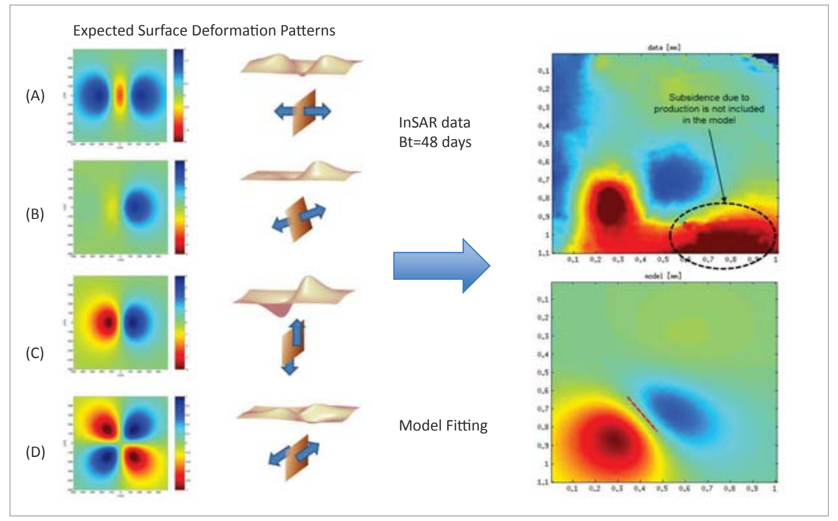

Figure 11: Suface deformation patterns in fault investigations.

Conclusions

Satellite observations offer the opportunity to observe large areas of the Earth's surface in great detail. Since the early 1990's InSAR has been part of a suite of satellite-based remote sensing techniques.

InSAR works on a 24-hour basis; does not require solar illumination in order to collect imagery, functioning at night and in poor weather. Interferograms allow the delivery of a rapid interpretation of movement trends, allowing for the adjustment of steaming or water-flood programs to optimize reservoir production.

As a result, InSAR has developed from a simple measurement of ground elevation change to its present state; a powerful tool for active reservoir management.

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